Structure and Reactivity of 1D Nanostructures on High-Index Si Surfaces

Alison Baski, Virginia Commonwealth University, DMR 0207643

In this work, we study how nanostructures can be created by etching (or removal) of atoms from a variety of silicon surfaces. Since silicon is the "workhorse" of the semiconductor industry, it is a material of industrial interest.

To form nanostructures, we etch the surface by exposing it to oxygen gas at high temperatures (> 700 °C). By controlling the oxygen exposure and temperature, it is possible to tailor the size and shape of the resulting nanometer-sized features. The initial orientation of the silicon surface is also critical to the shape of the nanostructures. Figure 1 shows the formation of triangular nanoislands on the low-index (111) orientation, whereas Fig. 2 shows linear nanofacets on the high-index (5 5 12) surface.

We can therefore control the growth of nanometer structures on a silicon surface, which may then be used as growth templates for subsequent device structures.

Triangular Nanoislands on Silicon

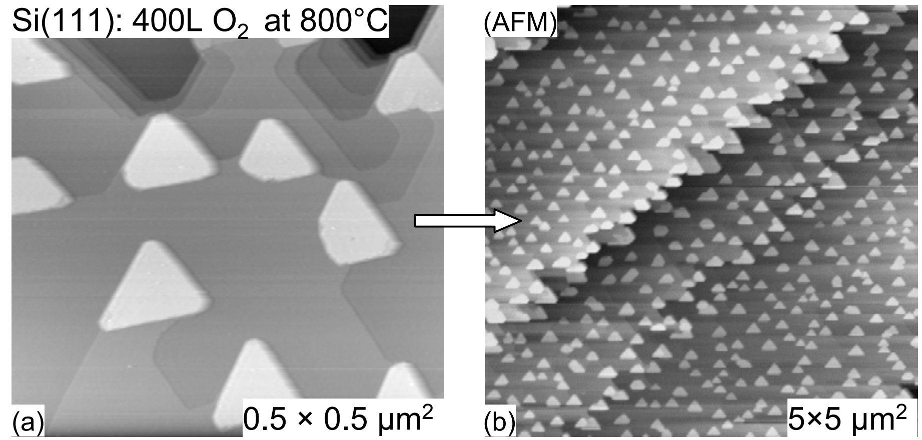

Fig. 1: Images show bright triangular islands formed by oxygen etching of silicon, where island size and density can be controlled by oxygen dosage and sample temperature.

Linear Nanofacets on Silicon

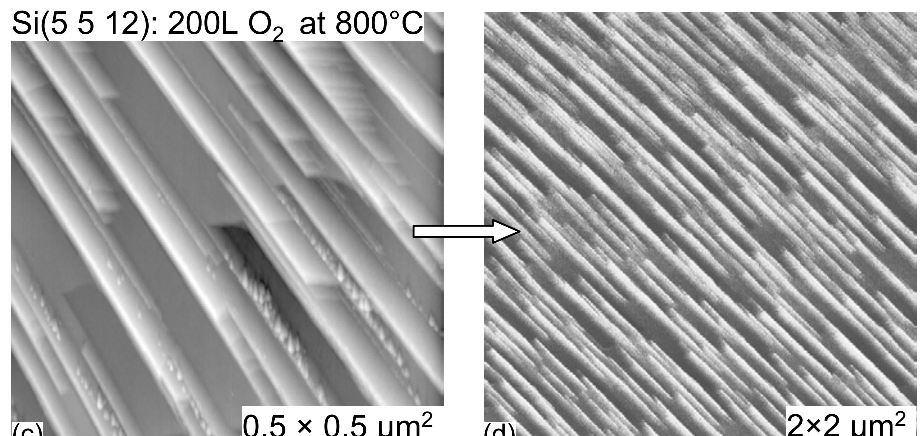

Fig. 2: A "tilted" orientation of silicon under similar etching conditions produces linear, sawtooth "nanofacets."

AIM OF THE PROJECT:

This research is a fundamental study of how nanostructures can be formed on high-index silicon surfaces, e.g. Si(113) or Si(5 5 12), by either deposition of metals or etching via oxygen. High-index surfaces are expected to show different behavior from their low-index counterparts, because they are anisotropic with linear surface structures oriented along the [-110] direction.

RESEARCH RESULTS:

We have used the techniques of ultra-high vacuum scanning tunneling microscopy (STM) and ambient atomic force microscopy (AFM) to study the temperature and oxygen dosage effects of etching on the Si(111), Si(5 5 12), and Si(113) surfaces. At low dosages (<50 Langmuirs) and moderate temperatures (700 to 750 C), these surfaces all show island structures near step edges caused by oxide-induced pinning sites. At high dosages (>200 L) and high temperatures (800C), etching has progressed so that nanostructures with low-energy planes are formed. In particular, triangular islands form on the low-energy Si(111) surface (see Fig. 1), whereas sawtooth nanofacets form on the high-energy Si(5 5 12) surface (see Fig. 2). The size and density of these nanostructures can be controlled by both the oxygen dosage and sample temperature.

SIGNIFICANCE OF THIS WORK

The ability to manipulate silicon surfaces at the nanometer scale may find applications in the growth of overlayers for electronic device structures.

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Education

Over the past three years, this grant has helped to support one Ph.D. student (Jonathan Dickinson), four M.S. students (Elizabeth Morris, John Skrobiszewski, Pat Woodworth, Mary Willis), and two undergraduates (Matthew Sievert, Lindsay Hussey). As part of their research, these students were trained to operate an ultra-high vacuum scanning tunneling microscope and ambient atomic force microscope.

Dr. Baski and Lindsay Hussey help 4th graders learn about series and parallel circuits at George Mason Elementary in Richmond City .

Outreach

Graduate and undergraduate students in this grant have also been involved with the physical science outreach program directed by Dr. Baski (also partially supported by federal NCLB funds). During the past two years, this program has delivered model physical science lessons to the classrooms of over 40 teachers at Richmond City Elementary schools. Dr. Baski offers a summer course for the teachers, and then follows up with classroom visits during the school year.

Two students are pretending to be “lightbulbs” connected in parallel to the “battery” modeled by Lindsay.